PARALLEL SESSIONS 3

3B / Sustainable diets and households behaviour

Environmental impacts of farms integrating aquaculture and agriculture in Cameroon

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ABSTRACT

Four farms integrating aquaculture and agriculture in the western highlands of Cameroon were analysed from 2005-2007 using Life Cycle Assessment (LCA) to better understand the contribution of fish-pond systems to regional sustainable development. LCA was conducted according to previous studies on aquaculture production using economic allocation and one tonne of fish production as the functional unit. The system boundary included on-farm processes, production of feed and fertiliser, fingerlings, and transportation at all stages. Dynamics of nitrogen and phosphorus were evaluated using a nutrient mass-balance modelling approach. Fertilisation of ponds with manure and crop by-products increased nutrient cycling; nevertheless, low quantities of nitrogen and phosphorus were assimilated by the fish. The main processes contributing to impacts were pig-manure fertilisation followed by feeding of wheat bran. Potential Eutrophication impact per tonne of fish produced was higher for these farms than that of other aquatic production systems due to the low efficiency of the system and the origin of nutritive inputs.

Keywords: fish pond, LCA, polyculture, catfish, tilapia

1. Background and objectives

In sub-Saharan Africa, fish constitutes 50% of human protein consumption. The fish originates mainly from fisheries and is distributed dried or frozen. Although aquaculture in sub-Saharan Africa is a recent activity, it increased up to 13% per year from 1970-2006 (FAO, 2007). Fish is produced mainly in ponds and could help to diversify family-scale agricultural production; it also can be a source of high-quality protein for local populations. Nevertheless, inland fish farming is developing slowly due to the lack of biotechnological knowledge of this activity by producers. We used Life Cycle Assessment (LCA) to put out main points requiring an intervention for fish farming development which hence of the amelioration of the global system productivity. This approach could help to improve the activity and the use of inputs by the farms, to better understand the contribution of fish-pond systems to regional sustainable development, in a perspective of alleviation of poverty in tropical areas. Nevertheless, environmental constraints are not considered as a major issue by the local population.

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2. Methodology: Goal and scope

The study was carried out in two regions of the western highlands of Cameroon (Alou and Fokoué districts), during two periods: (1) 2005-2006 and (2) 2007. Altitude and temperatures varied from 1000-2700 m and 16-27°C, respectively. Annual rainfall totalled about 1600 mm. Population density was about 143 inhabitants/km², and agriculture occupied 98% of the rural population (INS, 2006).

Four farms were chosen after categorising inland fish production systems, based on their level of production and ability to obtain inputs to feed fish. In all the farm systems, fish production was a polyculture of tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) at stocking densities of 3.0-5.5 fish/m². The first one (F1) was an integrated pig-and-fish pond system continuously fertilised by pig manure, complemented by the addition of wheat bran for direct fish feeding. The second one (F2) used wheat bran as fish feed and had ample access to inputs.(7272 kg pig manure, 405 kg wheat bran and 480 kg wheat bran) The third one (F3) was fertilised with a lower-quality pig manure and 50 kg crop by-products. The fourth (F4) was fertilised by pig and chicken manure (1940 and 120 kg respectively). As basic fertilisation, all farms received 0.15kg/m² of chicken manure. The first, second and fourth farms were owned by two church organisations, the third one by an independent small farmer. Pig feed ingredients of farms and their origins are summarised in Table 1.

Table 1: Pig feed ingredients (in %) of farms and their origins.

Ingredient	Farm			Origin
	F1	F3	F4	
Wheat bran	40	97	60	France
Maize	16	0	0	Cameroon
Soya cake	12	0	5	Brazil
Cotton cake	15	0	5	Cameroon
Palm kernel cake	0	2.5	26.4	Cameroon
Fish meal	12	0	0	France
Bone meal	2	0	0	Cameroon
Concentrated pork	3	0.5	4.6	France

LCA was conducted according to previous studies on aquaculture production (Papatryphon *et al.*, 2004ab; Roque d'Orbcastel, 2008; Casaca, 2008; Aubin *et al.*, 2009) using economic allocation and one tonne of fish production (tilapia plus catfish production) as the functional unit. The inventory was conducted for the duration of one production cycle: from the seeding with fingerlings up to harvesting. Farm data were obtained by direct measurement and farmer surveys. A data-collection system was established based on a record book daily filled in by the farmer. The system boundary included on-farm processes, feed and fertiliser (manure) production, harvest of catfish fingerlings, production of tilapia fingerlings, and transportation at all stages (Fig. 1). Impact categories examined were Potential Eutrophication (PE), Potential Climate Change (PCC), Potential Acidification (PA), Water Dependence (WD), Non-Renewable Energy Use (EU) and Net Primary Production Use (NPPU). Flows of nitrogen and phosphorus in these systems were evaluated using a nutrient-balance modelling approach (Cho and Kaushik, 1990) where only the fixed nutrients by fish are taken into account the rest are considered as rejected. This ignores the complex functioning of ponds, in which most nutrients in semi-intensive systems are sequestrated in pond sediments. The quantity of total nitrogen and phosphorus inputs were calculated from the chemical composition of manure and other inputs (Mohanta *et al.* 2006;

Pouomogne, 2005; Kumar et Ayyapan, 1998; Tuan *et al.* 2006). Fish corporal nutrient compositions were extracted from published data (USDA, 1998; Aquimer, 2010). Rejected nutrients (N or P) were estimated as the difference between the sum of inputs minus outputs contained in harvested fish.

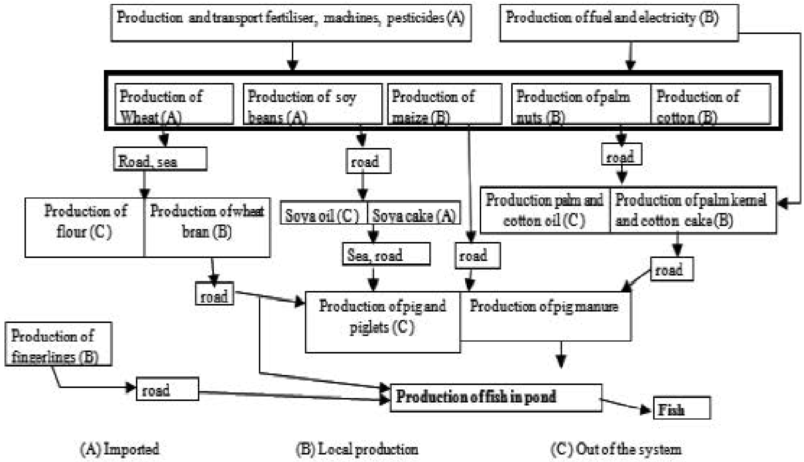
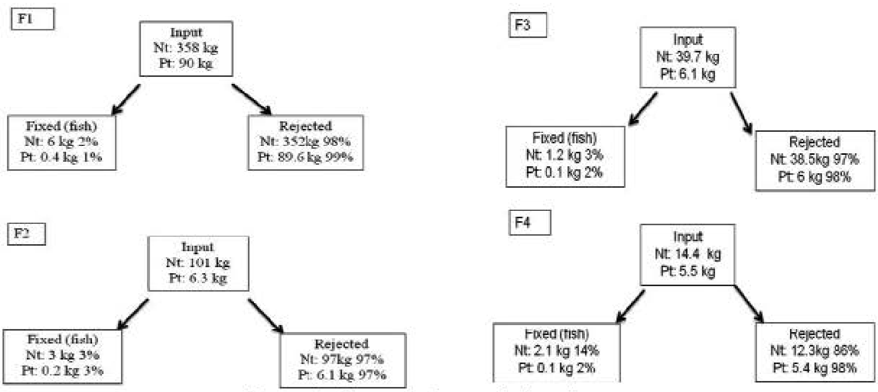


Figure 1: Flowchart of an inland fish farming system in Cameroon

3. Results

3.1. Dynamics of nitrogen and phosphorus

The dynamics of nitrogen and phosphorus for each production cycle in each farm were evaluated using nutrient-balance modelling, as summarised in Fig 2.



Nt: total nitrogen; Pt: total phosphorus

Figure 2: The estimated allocation of nitrogen and phosphorus in the four aquaculture systems

Although the aquaculture systems were intended to increase the recycling of manure and crop by-products, low quantities of N and P were fixed by the fish in these systems. Verdegem (2007) observed that pond culture systems are not efficient for nutrient use; only 5-25% of N, 20% of organic carbon and 5-18% of P of nutrient input was recovered in harvested fish or shrimp in semi-intensive ponds. The low assimilation of nutrients observed in these pond systems can be due to their poor water management (water renewal too high) and the low efficiency of the tilapia-catfish co-culture.

3.2. Environmental impacts

The potential environmental impacts of one tonne of fish product in the studied farms was compared to a Brazilian carp polyculture (*Ctenopharyngodon idella, Hypophthalmichthys molitrix, Hypophthalmichthys nobili, Cyprinus carpio*) associated to crop-production system (PV) and to intensive rainbow trout (*Oncorhynchus mykiss*) farming system in France, France (TF), as shown in Table 2.

Table 2: Potential impacts of different farms per tonne of fish produced compared to a fish polyculture and crop-production integrating system (PV; Casaca, 2008) and an intensive trout farming system (TF; Aubin *et al.*, 2009a) calculated with SimaPro 2.0 (modified CML 2001 method)

Impact Category		Farm					
	Unit	F1	F2	F3	F4	PV	TF
Potential Eutrophication (PE)	kg PO_4-eq.	908	318	401	157	23	66
Potential Climate Change (PCC)	kg CO_2-eq.	5091	1560	752	608	1150	2735
Potential Acidification (PA)	kg SO_2-eq.	22	7	3	3	8	19
Energy Use (EU)	MJ	17,039	4008	1829	1697	11,600	78,229
Net Primary Production Use (NPPU)	kg C	8653	1038	1011	1671	2330	62,200
Water Dependence (WD)	m^3	16,879	19,982	5137	23,705	6290	52,600

F1: integrated pig-and-fish system; F2: wheat bran as fish feed; F3: pig manure and crop by-products; F4: pig and chicken manure; PV: Peixe-verde (fish polyculture integrated with crop production, Brazil); TF: intensive rainbow trout production (Brittany, France).

Potential eutrophication of the four Cameroonese farms was higher than that of the Brazilian semi-intensive fish polyculture integrating crop production (PV) and the French intensive trout production (TF). Poor water management of ponds and lack of nutrient utilisation due to inappropriate fish polyculture and nutrient management might have been the main causes. Xie *et al.* (2007) concluded that an appropriate polyculture increases the fixation of nutrients in ponds (and improves the profit margins of aquaculture), hence decreasing the nutrient loading into natural water bodies that causes eutrophication. Differences observed within Cameroonese farms are linked to their poor water and nutrient management. Considering the sequestration of nutrients in pond sediments, which can be used as input for the next cycle or removed and used as fertiliser for crop production, may increase estimates of the percentage of input nutrients ending up in harvestable products.

As observed in the Brazilian Peixe-Verde system, energy consumption was lower than that in the French trout system due to the lack of mechanisation either at the pond-construction stage or during the rearing period. Higher levels of impacts observed in Farm 1 (F1) compared to other Cameroonese farms was due to the quality of food ingredients and the management of the system. Water dependence of Cameroonese farms was higher than that observed by Phillips et *al* (1991) in semi-intensive Israelin farms (5000 m^3/t fish) but lower than that in French intensive trout production (52,600 m^3/t fish), despite the variability of water use in different aquaculture systems and different areas. Verdegem and Bosma (2009) concluded that the social, economic and environmental contexts in which farmers live are important factors regulating water use. The contribution of different processes to impacts on farms (relative to those of farm 1 (F1)) are illustrated in Fig 3.

It seems that apart from potential eutrophication and water dependence, which depend solely on the fish-production process (which needs major improvements in Cameroon), several processes were responsible for each impact. Indeed, the main processes contributing to impacts were pig-manure fertilisation and feeding of wheat bran, partly due to the foreign origin of the wheat and other feed ingredients for pig production combined with their low feed-utilisation efficiencies. Potential eutrophication impact per tonne of fish produced was higher for these farms than that of other aquatic-production systems due to their poor management and the origin of feed ingredients.

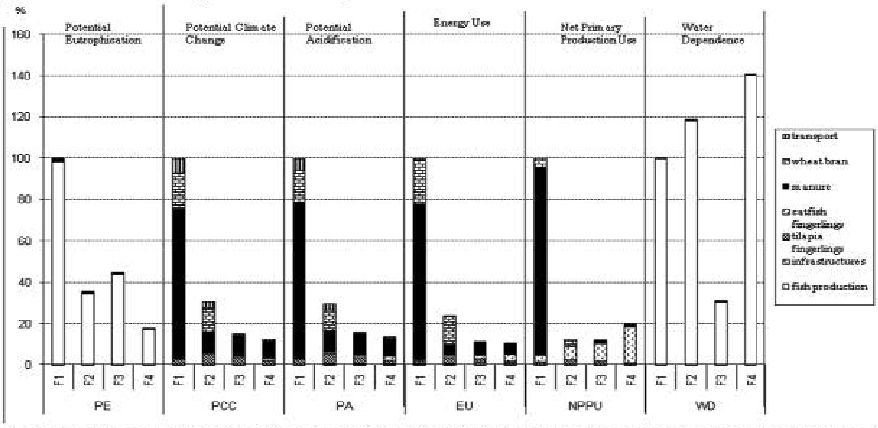


Figure 3: Relative contribution (compared to F1) of processes to impact categories per tonne of fish produced for the four farms studied.

4. Conclusions

Fertilisation increased the recycling of manure and crop by-products and decreased potential environmental impacts. Nevertheless low quantities of nitrogen and phosphorous were fixed by the fish in these systems. Potential eutrophication impact per tonne of fish produced was higher for these Cameroon farms than that of other aquatic production systems, but eventually taking into account gaseous emissions from ponds and the use of pond sediments in the agricultural system may reduce this impact. . The main processes contributing to impacts were pig-manure fertilisation and the feeding of wheat bran. Our results show that agriculture systems considered as extensive and low-input are not necessarily less polluting than intensive European ones. The question of yields and efficiency is a central point to better characterise systems, which argues for the use of LCA. Future field experiments using a fractional design will be conducted to identify ways of optimising the productivity of these systems. Nutrient-flow evaluation methods need improvement to be suitably adapted to pond systems. For each route a better understanding of processes explaining nutrient dynamics in ponds will be instrumental for developing sustainable integrated aquaculture-agriculture systems.

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